Dynamic Material Studies in Subcritical Experiments: Rocco, Mario, Vito, and Armando

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Members of P-22 and P-23 in collaboration with DX, ESA, MST, and X Divisions and with international and national organizations designed and executed a series of SCEs, known as the Stallion series (Vito, Mario, Rocco, and Armando). Mario and Rocco were executed to evaluate the properties (principally strength) of cast and wrought plutonium samples driven by high explosives. Vito was conducted primarily to look at ejecta in a particular region of a weapon. The cast and wrought samples used in our experiments were representative of the materials produced via the different manufacturing processes employed at Rocky Flats and LANL. The specific properties investigated in this series included ejecta production, spall features, and surface temperatures. “Ejecta” is small particulate matter that is “ejected” from the surface of a solid when a strong shock wave interacts with the surface. “Spall” is a general term used for bulk-material failure at the surface of a solid created by a strong shock interacting with the surface. Both ejecta and spall formation depend upon, for example, material strength, grain size, impurities, and other material properties and upon the strength and temporal profile of the shock pressure. An important constraint upon the final state of a shock-driven metal is the surface temperature—which will help further our understanding of the behavior of shocked material.

Vito—Demonstrating a New Technique for the Rapid Turnaround of Subcritical Experiments

Vito, the first SCE in the Stallion series, was fired successfully on February 14, 2002, in the U1a complex at NTS.[1] The experiment—a very successful collaborative effort with LANL, Bechtel Nevada, and the Atomic Weapons Establishment (AWE)(United Kingdom)—achieved a number of important milestones, including the re-establishment of a long-standing LANL-AWE collaboration in performing experiments at the NTS. These historical experiments had been closely aligned with joint theoretical and experimental weapons physics objectives, which are now more focused on maintaining a nuclear-weapons capability without nuclear testing. The second milestone achieved by Vito was a highly successful demonstration of the LANL “racklet” technique (Figure 1). This technique permits the rapid and cost-effective turnaround between SCE experiments with a reuse of diagnostic “clean-room” areas downhole.

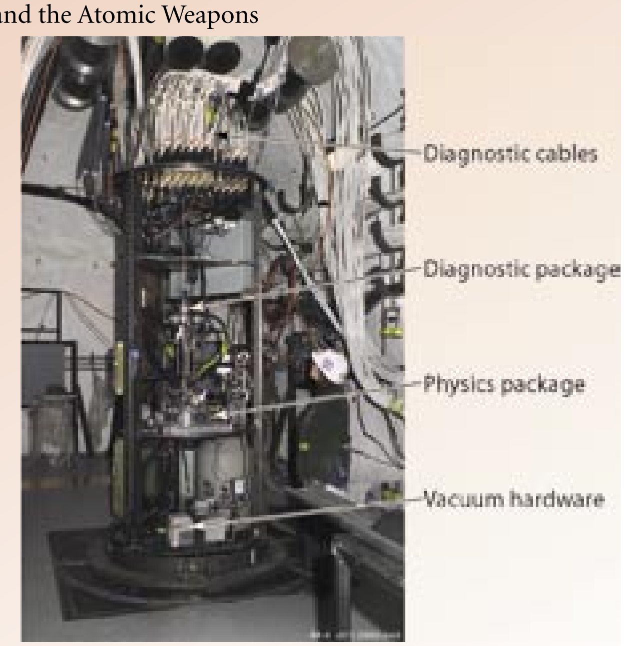
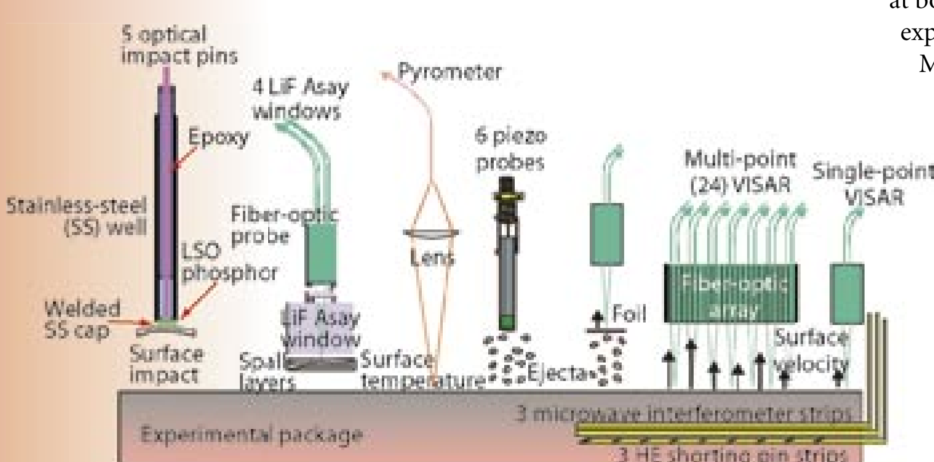


Figure 1. The Vito racklet assembly before it was lowered into the confinement hole.

We obtained a unique data set of high-quality measurements by combining LANL-AWE experimental techniques. Piezoelectric probes[2] and Asay foils coupled with a laser and streak camera system to record Fabry-Perot and VISAR signatures[3] led to results that enhanced our understanding of the generation of ejecta particles and the distribution of spatially dependent surface velocities. AWE and LANL each provided specialized diagnostics for characterizing the detonation properties of the physics package. Both the physics and the diagnostic packages were shipped separately to the NTS from the AWE and were assembled and installed in the U1a complex. A small team of engineers and diagnostic specialists from AWE were the primary leads for the physics package and the diagnostics measurements. (Improvements to the timing and firing system resulted in an optimized system for future SCEs.) LANL provided electronic readouts for streak cameras that resulted in excellent signal-to-noise ratios in the AWE Fabry-Perot-based velocity measurements. LANL specialists also fielded a VISAR system for data comparison.

In the newly tested racklet technique, both fiber optic and electrical cables enter the experimental chamber from the lid and are routed to the timing and firing system, the energy-release package, the physics package, and the diagnostic package. The diagnostic cables are routed through a secondary containment bulkhead to recording and clean rooms that house digital oscilloscopes, streak cameras, and lasers. We procured special auger equipment to drill a 5-ft-diam, 35-ft-deep confinement hole into the drift invert (tunnel floor). In preparation for the Vito event, the racklet assembly was lowered into a canister that had already been placed into the augered hole to protect the experiment from the surrounding material that would fully confine the experiment. After the Vito event, the cables were cut and moved to a neighboring hole for reuse in another experiment.

Figure 2. Schematic of the diagnostics used on the Mario and Rocco SCEs.



The Vito event demonstrated the success of the racklet technique for SCEs. Through repeated subsequent SCEs, the overall efficiency of the technique was improved, and it now provides a LANL-demonstrated rapid-turnaround capability for the U1a complex. The success of the Vito event resulted in the design of a more complex follow-on collaborative experiment with AWE at the NTS U1a complex.

Mario and Rocco—Addressing the Generation and Dynamic Development of Spall

Mario and Rocco followed the Vito experiment in a collaboration that involved personnel from LANL, SNL, and Bechtel Nevada. The P Division experiments provided important data related to spall, ejecta, and the surface temperature of shocked plutonium in a weapons-relevant geometry. The Rocco and Mario diagnostics and package designs were identical, but Rocco provided data on the physical property of cast plutonium at conditions approaching those found in nuclear weapons to complement the data on wrought plutonium obtained from the Mario experiment.

Like Vito, Mario and Rocco used the racklet technique (described above) for deployment and execution of the physics experiments. But unlike Vito, two "confirmatory" experiments were executed as "dry runs" for Mario and Rocco in 6-ft-diam confinement vessels in the "G" drift region of the U1a complex. Normally conducted at LANL before being executed at the NTS, these confirmatory experiments were conducted at the NTS to better match component delivery schedules, to save time in setting up the diagnostic recording systems, and to eliminate the need to build recording cable plants at both LANL and the NTS. The confirmatory experiments and diagnostics were identical to Mario and Rocco except for the confinement spheres and the use of specially designed surrogate alloys instead of plutonium. Because these surrogate alloys exhibited some of the properties of plutonium, the confirmatory experiments were not only important as dry runs for Mario and Rocco, but they also provided useful data to help interpret the data from Mario and Rocco. The combination of the confirmatory experiments and the actual events were executed with rapidity reminiscent of the heyday of underground nuclear testing.

The Mario and Rocco experiments addressed material-physics issues (in particular, the generation and dynamic development of spall) that were used in computer simulation codes to model the nuclear-explosion process. The high-quality data obtained from Mario and Rocco were important both for their significance to the SCE program and for execution of the upcoming Armando SCE (described below), which will image identical experimental packages via x-ray radiography to measure the spatial distribution of the spall layers. Rocco used the same diagnostic suite as Mario to make a direct comparison between the behavior of wrought and cast plutonium under shock conditions.

The diagnostics used in the Mario and Rocco shots (Figure 2) included line VISAR, point VISAR Asay foil (which measures ejecta mass), Asay windows, piezoelectric probes, optical pins, and infrared pyrometry. Electrical pins and flat Mylar microwave-interferometry strips inside the high explosive measured its performance. P Division and SNL developed the Asay-window diagnostic for the Mario and Rocco experiments. Information on the state and thickness of the spalled layers below the target surface can be inferred by allowing these layers to collide in a "domino fashion" into an LiF window and by observing the change in velocity of the metal-LiF interface. A number of small high-explosive-driven experiments were conducted in firing chambers at DX and at the LANL pRad facility to validate individual diagnostic techniques, particularly the Asay window technique, with modeling support from X Division.

Armando—Verifying Surface Behavior Observed on Mario and Rocco

Armando—the last of the SCEs in the Stallion series to be executed in April 2004—will use a reduced set of the diagnostics deployed on Rocco and Mario, including point VISAR, surface velocity diagnostics, and optical pyrometers, to verify the behavior of the target surface observed in the Rocco and Mario shots. The primary diagnostic for Armando will be x-ray radiography along two equivalent axes separated by 60°. Physics packages identical to those used in the Rocco and Mario shots will be combined in a hexagonal (HEX) package (six sides) vertically separated with the free surfaces facing one another. This geometry will allow us to obtain equivalent x-ray radiographs of the two materials at the same time in their dynamic evolution. The third axis of the HEX package will be used for VISAR and pyrometry access.

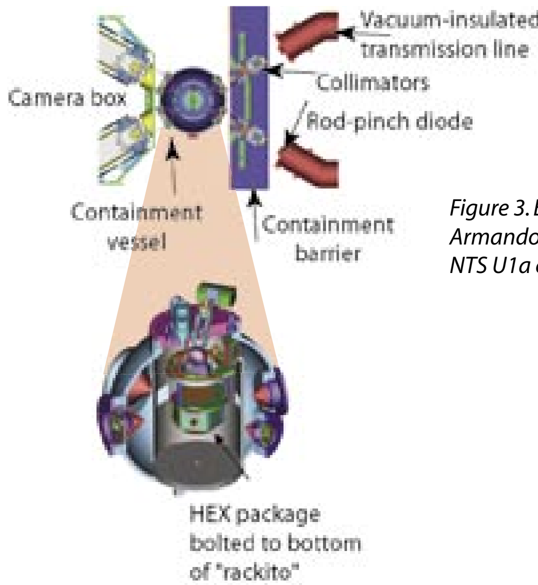


Figure 3. Experimental layout of the Armando x-ray radiographic system at the NTS U1a complex.

The experimental package will be in a 3-ft-diam (inside diameter) confinement vessel. This vessel and a camera box that houses an x-ray-to-light-converting scintillator and camera system will be placed within a "zero room" created by a large bulkhead. (The term "zero room" is derived from "ground zero"—the location on the surface beneath which a nuclear event was detonated in the days of underground testing. The SCE is contained within the zero room.) Thin radiographic windows in the bulkhead and confinement vessel allow x-rays to pass through the package and the confinement vessel with minimal attenuation (Figure 3). By fielding the experiment within a confinement vessel, the zero room can be reused for multiple experiments.

The Cygnus x-ray sources (Figure 4) will extend down a drift external to the zero room. These sources will be composed of a Marx bank system, which will be contained in a large oil-filled tank that will pulse-charge an adjacent pulse-forming line (PFL). The output of the PFL will be a short (60 ns), large-amplitude (1 MV) electrical pulse that will propagate down an 8-in.-diam, water-filled, coaxial transmission line. This electrical pulse will be coupled into inductive voltage adder cells that will add the voltage in parallel to produce a 2.25-MV low-impedance drive pulse for the rod-pinch diode. This last stage of voltage addition will be accomplished in a high vacuum suitable for diode operation.

The radiography that will be used on the Armando SCE represents a significant leap in performance. It

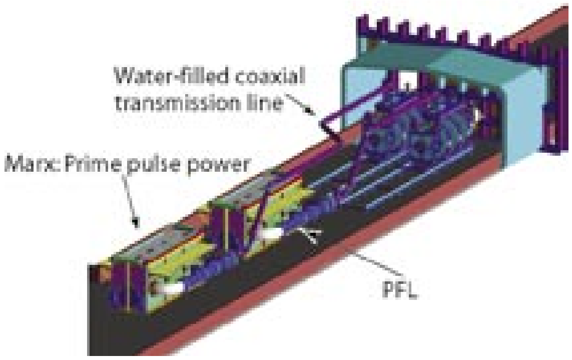


Figure 4. Layout of Cygnus x-ray sources in the U1a.05 drift (tunnel) at the U1a complex.

has been the result of a multi-year, multi-laboratory effort involving LANL, SNL, AWE, Bechtel Nevada, the Naval Research Laboratory (NRL), the Titan Corporation Pulse Sciences Division, and the Mission Research Corporation. Many innovations have combined to lead to this leap in performance, but perhaps the most important has been the effective realization of the rod-pinch diode originally developed at NRL. The rod-pinch has a similar geometry to standard x-ray diodes that have been used in industrial flash x-ray sources for several decades. However, NRL discovered that, when operated at low impedance (large currents at ~ 40 kA), the diode would transition from classic space-charge-limited flow into magnetically limited flow, whereby the electrons would be transported to the end of the central anode rod and then "pinch," thus producing a very bright, small diameter x-ray source. The Cygnus x-ray source was designed to provide a low-impedance source of voltage to effectively drive the diode into the magnetically limited regime. Measurements have demonstrated a 1-mm-diam x-ray spot that produces 4 rad at 1 m in a reproducible manner.

The detector system is equally innovative. It combines technologies developed for DARHT and pRad to create a very high-resolution imaging system. The detector converts the x-rays transmitted through the experimental package into visible light in a tiled, cerium-doped LSO (lutetium oxyorthosilicate) scintillator, which makes the high efficiency and high resolution of the detector system possible. The light produced is transported by a lens system to an LN_2-cooled charge-coupled-device (CCD) chip that captures and records the image. To preserve maximum image resolution, the combined CCD camera system is not gated; all time resolution therefore derives from the flash nature of the illuminating x-ray pulse. The scintillator-camera combination must, however, be maintained in a light-tight configuration throughout the high-explosive detonation and long enough thereafter (~ 30 s) for the information to be read out of the CCD camera system to a remote data-logging computer.

Conclusion

To date, the Stallion SCE series has provided high-quality information of critical importance to the LANL design effort while simultaneously helping to reinvigorate the mutually beneficial collaboration with AWE on weapons-physics experiments. Execution of the final experiment in the series—Armando—will provide high-quality radiographic data previously unobtainable and will result in a facility that is ideally suited to further investigate the dynamic properties of plutonium under shock loading.

References

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